Assessment of the Degree of Activity of Abrasive Particules in the of Machine Components Involved in the Wear Process

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Abstract: This article considers the regularities of abrasive particles activity changing in the oil of machine units, which take part in the process of gear-wheel wear at constant and increasing concentration varying with the number of loading cycles of gear teeth, considering the share of crushed abrasive particles in one loading cycle of the gearing which is used to determine the oil replacement time in the machine unit.

1 INTRODUCTION

One of the factors that most significantly affect the results of calculation and experimental determination of the wear resistance of gear materials is the degree of activity of abrasive particles in the oil of machinery transmission units.

In the process of friction for each cycle of loading of gear teeth, the concentration of active abrasive particles in the oil of the machine constantly changes. It occurs because of crushing of abrasive particles, being in oil of the aggregate and entering of a fresh portion from environment (Ishmuratov, 2019; Mirzaev et al., 2019; Mamatov et al., 2021; Mirzakhodjaev et al., 2021; Khudayorov et al., 2023; Khudayorov, et al., 2023; Khudayorov,et al., 2023; Mirzakhodjaev et al., 2024; Mirzakhodjaev et al., 2024). Therefore, when assessing the wear resistance of gear teeth and the oil change period in the units it is necessary to consider the regularities of abrasive particles activity change in the process of oil circulation. Analysis of the state of the matter in question showed that in the literature this issue is not sufficiently covered, mainly limited to the study of the process of crushing abrasive particles located in the contact zone of gear teeth (Ishmuratov et al., 2020; Djiyanov et al., 2022; Astanakulov et al., 2023; Djiyanov et al., 2024; Djiyanov et al., 2024; Isakova et al., 2024; Irisov et al., 2024).

The purpose of this work is to obtain computational dependences for estimating the activity of abrasive particles, at their constant and increasing concentrations.

2 MATERIALS AND METHODS

In heavily loaded gears, the load falling on the abrasive particles in the wedge-shaped gap of gear teeth, in most cases exceeds their compressive strength, as a result of which these particles are subjected to crushing (Zhigaev, 1971; Melnikov, 1999). Because according to (Mirzakhodjaev et al., 2024) the coefficient of re-crushing of abrasive particles equal to 7, after crushing process, the size of crushed abrasive particles should not exceed:

$$da<Rz+h_0, \text{ m}, \tag{1}$$

where R_z is the roughness height of the friction surfaces of the gear teeth, m; h0 is the thickness of the oil film between the friction surfaces of the gear teeth, m.

In the process of gear teeth wear, abrasive particles of the size corresponding to expression (1)

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do not come into force interaction with friction surfaces, and wear from their influence does not occur.

The total concentration of abrasive particles in the oil of the unit can be constant and increasing in time, because of their penetration from the environment. Let us see how the abrasive particles activity changes for these cases.

3 RESULTS AND DISCUSSION

The total concentration of abrasive particles in the oil is constant, its value in time remains constant, i.e., no new portions of abrasive particles enter the oil from the outside. This variant is characteristic for testing of roller samples of cogwheels for wear resistance on the friction machine MI-1M. The size of abrasive particles used for wear testing should be greater than the sum of the roughness height and oil film thickness (exceeding 4 microns). In this case, the initial concentration of abrasive particles in the unit oil was taken equal to their total concentration (ε_{max}).

At crushing of active abrasive particles, depending on number of loading cycles, their concentration decreases (fig.1, graphs 1, 2). Let us consider changes of abrasive particles activity in the process of wear resistance test, after each loading cycle. Loading cycle is one complete revolution of a spherical toothed wheel specimen, which is dipped into oil containing abrasive particles of spherical shape (Irgashev et al., 2021; Ishmuratov et al., 2023).

After the first load cycle:

The concentration of crushed abrasive particles,

$$\varepsilon_{1d} = \varepsilon_{\max} A_1 , \qquad (2)$$

where A_1 is a coefficient taking into account the share of crushed abrasive particles for one cycle of loading, at constant total concentration of abrasive particles in oil. For calculation of A1 value the dependence is offered (Djiyanov et al., 2024b),

$$A_1 = \frac{2\pi R l d_{cp} \gamma_m}{G_{m.t}} , \qquad (3)$$

here R - radius of curvature of sample, surrounding in oil, m; dcp - average size of abrasive particles, participating in wear process, m; 1 - contact length of samples, m; γ_m - oil density, kg/m^3; Gm.t - amount of oil, poured into friction machine tank at test on wear resistance of samples, made of cogwheel material, kg,

concentration of active abrasive particles in the friction machine oil after the first loading cycle,

$$\varepsilon_1 = \varepsilon_{\max} (1 - A_1) .$$

After the second loading cycle:

The concentration of crushed abrasive particles,

$$\varepsilon_{2d} = \varepsilon_1 A_1 = \varepsilon_{\max} (1 - A_1) ;$$

concentration of active abrasive particles,

$$\varepsilon_2 = \varepsilon_1 - \varepsilon_{2d} = \varepsilon_{\max} A_1 (1 - A_1) = \varepsilon_{\max} (1 - A_1)^2$$

Similarly, after k loading cycles:

The concentration of crushed abrasive particles,

$$\varepsilon_{kd} = \varepsilon_{k-1} A_1 = \varepsilon_{\max} A_1 (1 - A_1)^{k-1} , \qquad (4)$$

concentration of active abrasive particles,

$$\varepsilon_k = \varepsilon_{\max} (1 - A_1)^k . \qquad (5)$$

The obtained analytical dependencies show that at constant total concentration of abrasive particles, which are in oil, increase of abrasive particles size, radius of curvature and width of contact of samples, made of toothed wheels material, dipped in oils in the friction machine tub, leads to growth of their crushing intensity. This is explained by the fact that increasing the radius of curvature leads to a narrowing of the wedge-shaped gap between the samples of the friction process, leading to an increase in the contact area between the surfaces of samples and abrasive particles, due to which, increases the number of adhered and crushed abrasive particles on the contact surfaces of friction (Akhmetov et al., 2021; Zhanikulov et al., 2022; Akhmetov et al., 2023).

The received analytical dependences show that at constant total concentration of the abrasive particles being in oil, the increase in size of abrasive particles, radius of curvature and width of contact of the samples made of gear wheel material dipped in oils in the bath of friction machine leads to increase in intensity of their crushing. This is explained by the fact that increasing the radius of curvature leads to a narrowing of the wedge-shaped gap between the samples occurring in the friction process, leading to an increase in the contact area between the surfaces of samples and abrasive particles, thereby increasing the number of adhered and crushed abrasive particles on the contact surfaces of friction.

2. The initial concentration of abrasive particles in the oil of the unit is zero; it increases with increasing number of loading cycles of the driven gear (fig. 1, graphs 3, 4). This case corresponds to the real operating conditions of the gear transmission in the unit.

Let us assume that tightness of crankcase and dustiness of environment during exploitation of machines remain constant. As a result, penetrated abrasive particles from the environment are subjected to crushing and the concentration of active abrasive particles in the machine oil changes constantly during each load cycle (Akhmetov et al., 2023).

After the first loading cycle of the gear wheel: concentration of crushed abrasive particles,

$$\varepsilon_{1d} = 0 ,$$

concentration of active abrasive particles,

$$\varepsilon_1 = \delta_z ,$$

where is the number of active abrasive particles entering the unit oil during one cycle of the driven gear loading, % rev.

After the second cycle of gear wheel loading: concentration of crushed abrasive particles is,

$$\varepsilon_{2d} = \delta_z B$$

where B - the coefficient taking into account the share of crushed abrasive particles at their arrival from the environment, corresponding to the operating conditions of machine units,

$$B = \frac{2n_1 m d_{cp} L \gamma_m k_p}{G_m} \quad (6)$$

here n_1 - the number of gear pairs in the unit, dipping in oil; m - meshing module, m; L - gear tooth length, m; G_m- quantity of oil in the unit, kg; k_p - coefficient taking into account the heterogeneity of abrasive particles size that penetrate into the unit, depending on the dusty environment and abrasive particle size value in the oil $k_p = 0,40$ - 0,65,

$$\varepsilon_2 = 2\delta_z - \delta_z B = \delta_z (2 - B)$$

Similarly, after k1 cycles of gear wheel loading: concentration of crushed abrasive particles,

$$\varepsilon_{k_1 d} = \delta_z B (k_1 - 1) \quad (7)$$

concentration of active abrasive particles

$$\varepsilon_k = k_1 \delta_z - \varepsilon_{k_1 d} = \delta_z (k_1 - B(k_1 - 1)) \quad (8)$$

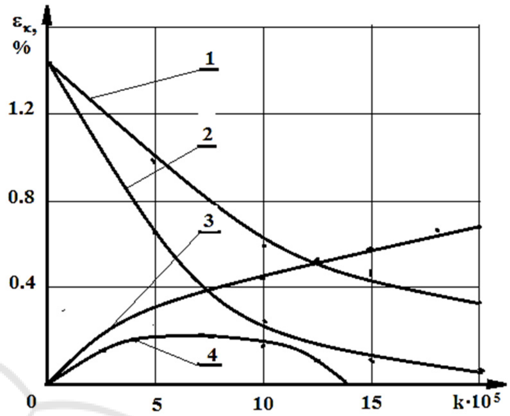

Figure 1: Change of concentration of active abrasive particles in aggregate oil from the meshing module and number of cycles of loading: 1, 2 - total concentration of abrasive particles in oil is constant; 3, 4 - the initial concentration of abrasive particles in aggregate oil is equal to zero and changing for each cycle of loading, 1, 3 – m = 0,010 m; 2, 4 – m = 0,015 m

Graphical dependencies presented in Fig. 1, obtained from expression (6 and 8) graphs 3, 4, constructed at: n_1=2; d_{cp}=0,000012 m; L=0,058 m; γ_m = 910 kg/m^3; k_p=0,5; G_m=20 kg; δ_z=0,65 10^{-6} %/rev show, that if initial concentration of abrasive particles in oil is zero, with increase of loading cycles concentration of crushed abrasive particles gradually increases, after its value reaches some critical value, it slightly decreases. This can be explained by the excessive amount of crushed abrasive particles in the oil of the unit compared to the abrasive particles coming into the unit from the environment.

4 CONCLUSIONS

Thus, the obtained expressions for determining the activity of abrasive particles (9) make it possible to calculate:

1. durations of wear testing of gear wheel material on samples at a constant total concentration of abrasive particles in the oil;

2. the period of oil replacement of units of machines with toothed gears, working in the presence of abrasive particles in the working environment

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